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## Repsold Company as a Global Player: From the First Meridian Circle in 1802 to the Modern Computerized in 1967

*La société Repsold comme acteur mondial : du premier cercle méridien en 1802  
au système informatisé moderne en 1967*

**Gudrun Wolfschmidt**

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## Repsold Company as a Global Player: from the First Meridian Circle in 1802 to the Modern Computerized in 1967

Gudrun Wolfschmidt

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**Abstract** — The first modern meridian circle after Rømer's *Rota Meridiana* (1704) was constructed by Johann Georg Repsold (1770-1830) in 1802, used in the first Hamburg observatory, restored for Göttingen, 1818. A new meridian circle, made by A. & G. Repsold for the Hamburg-Millerntor Observatory (1825), was installed in 1836. The large 19-cm-meridian circle for the new Hamburg Observatory in Bergedorf, was made by Adolf Repsold & Sons (1909) with impersonal micrometers, levels, mires. In 1967 the Hamburg meridian circle was equipped with photoelectric reading and computerized, and used in Perth, Australia, for a catalogue of stars of the southern hemisphere (until 1987). The topic is discussed in the context of Repsold meridian circles all over the world — the Repsold company as a global player.

**Résumé** — *La société Repsold comme acteur mondial : du premier cercle méridien en 1802 au système informatisé moderne en 1967 — Le premier cercle méridien moderne après la Rota Meridiana de Rømer (1704) a été construit par Johann Georg Repsold (1770-1830) en 1802, utilisé dans le premier observatoire de Hambourg, restauré pour Göttingen en 1818. Un nouveau cercle méridien, réalisé par A. & G. Repsold pour l'observatoire de Hambourg-Millerntor (1825), a été installé en 1836. Le grand cercle méridien de 19cm pour le nouvel observatoire de Hambourg à Bergedorf, a été réalisé par Adolf Repsold & Sons en 1909 avec des micromètres impersonnels, des niveaux, des mires. En 1967, le cercle méridien de Hambourg a été équipé d'un enregistrement photoélectrique, assisté par ordinateur, et utilisé à Perth en Australie pour un catalogue d'étoiles de l'hémisphère sud (jusqu'en 1987). Le sujet est discuté dans le contexte des cercles méridiens Repsold du monde entier — l'entreprise Repsold en tant qu'acteur mondial.*

Mots-clés : histoire matérielle, historiographie, histoire culturelle, sciences historiques, astronomie, instruments et instrumentation, époque contemporaine, cercle méridien, Repsold compagnie, astrométrie, catalogues d'étoiles, Hipparcos satellite

## 1. Introduction of the Meridian Circle

Ole Christensen Rømer (1644-1710) invented the meridian circle, called *Rota Meridiana*, in 1704 installed in his Observatorium Tusculanum — a highlight in instrument making. Rømer had first installed a transit instrument (*Machina domestica*) in a window facing south in Copenhagen (in his home in Store Kannikestræde 16), but this only covered a small section ( $69^\circ$ ) of the meridian. His aim was to measure stellar parallaxes in order to verify the Copernican system. This instrument was illustrated by his assistant Peder Nielsen Horrebow (1679-1764) in 1735 (Dorch & al., 2021). Rømer realized that a single instrument covering the full meridian would have a significant advantage, because stars could be observed to the north below the pole and the same stars again twelve hours later above the pole. In this way important constraints on the mounting errors of the axis could be established and easily monitored (Nielsen, 1968). This led him to design and build what would become the world's first meridian circle. In 1704, he finally managed to build a small observatory 17-km west of Copenhagen; there he installed a meridian circle and a transit instrument in the prime vertical. The meridian circle had a telescope, a divided circle, circle reading microscopes, and also meridian marks for adjusting the instrument (Nielsen, 1968). The meridian circle at Tusculum was used diligently only from 1705 to 1711, because Rømer died in 1710, and his assistant and successor L. Skive died during the plague of 1711. The instruments were transferred to the Rundetårn (Round Tower) Observatory in Copenhagen in 1716/17. Then, in 1728, nearly the whole body of observations was lost in the Fire of Copenhagen together with the instruments itself. Surviving the fire was a set of observations, the Triduum observations, from three days and nights 20-23 October 1706. These were finally published (Horrebow, 1735).

But this innovative idea of a meridian circle was, however, not adopted elsewhere, the mural quadrant continued until about 1800; it took time to realize that the accuracy of traditional instruments like the mural quadrant was insufficient. Only some transit instruments were used, like in Greenwich or in Mannheim.

Tobias Mayer (1723-1762) used Rømer's Triduum meridian observations together with his own observations from 1756 in his study of stellar proper motions — a study, which Friedrich Wilhelm Herschel (1738-1822)

used when discovering the apex-motion of the Sun. The next step in the development of instruments was the repeating circle, invented by Tobias Mayer in 1770, inspired by Ole Rømer. Mayer published his invention as *Nova methodus perficiendi instrumenta geometrica et novum instrumentum goniometricum* in *Commentaria Societatis Goettingensis* II (Göttingen 1752); later reprinted by Johann Friedrich Benzenberg (1777-1846) in 1812 (Benzenberg, 1812). At the end of the 18th century, following the ideas of Tobias Mayer, Jean-Charles de Borda (1733-1799) developed and produced the navigator's reflecting circle (around 1785), also José de Mendoza y Ríos (1761-1816) (1801), and Étienne Lenoir (1744-1832) (1805). Repeating circles were made by Bellet of Geneva (around 1800), also by Lenoir (1805), others later by Pistor & Martins of Berlin. This undoubtedly showed the usefulness of the instrument, the repeating circle with mirrors or prisms, for astronomy, navigation, and surveying, and paved the way in the direction to the invention of the modern meridian circle. The key feature is an improved reading of the results (4 times) — compensating dividing errors of the circle.

Some large transit instruments with a vertical and an azimuth circle were constructed e.g. by London instrument makers like Jesse Ramsden (1735-1800, F.R.S. 1786) for Palermo (1789), by William Cary (1759-1825), John Cary (1791-1816), and John Bird (1709-1776). In 1806, Edward Troughton (1753-1835, F.R.S. 1810) created the large Groombridge transit circle, which Stephen Groombridge (1755-1832) used in Blackheath for his star catalogue\*. (Chapman, 1983, p. 135) described the transition from the mural quadrant to the circle instruments as a leap in quality.

## **2. Johann Georg Repsold and the Invention of the Modern Meridian Circle**

In this paragraph it will be discussed how Johann Georg Repsold moved into the instrument making business, which contacts he had to the scientific community in Hamburg and Europe like astronomers and instrument makers, his comprehensive correspondence with famous astronomers, and his first own observatory (1802). Repsold visited the instrument makers in Munich, Zürich, France and England, got inspiration and impetus for his work (and vice versa), but both sides also tried to keep their secrets. Repsold's instruments for navigation, surveying and astronomy, especially his invention of the modern meridian circle, were highly appreciated by astronomers —

Gauß bought this revised first meridian circle for Göttingen Observatory. But due to his professional duties, Repsold could not deliver many instruments, so the Munich makers dominated the market for meridian circles until the early 1830s.

Johann Georg Repsold (1770-1830) got his training in hydraulic engineering and surveying technology with Reinhard Woltman (1757-1837) in Cuxhaven.<sup>1</sup> Since 1791/95, he became a surveyor's assistant to Johann Theodor Reinke (1749-1825) in Hamburg, and since 1796 as a conductor at the Elbe Deputation in Hamburg; Repsold constructed the lantern for the lighthouse on the island Neuwerk (1810) to mark the estuary of the river Elbe into the North Sea. In 1799, he was called as head of the Hamburg fire brigade (1798 Spritzenmeister, 1809 Oberspritzenmeister). In his official residence in *Herrengaben* 138 (later 224, now 85), he opened a mechanical precision workshop in 1799, and also for electrical apparatus.<sup>2</sup> Johann Georg Repsold was in contact with the astronomers and instrument makers Johann Caspar Horner (1774-1834), who got his training in Göttingen and Gotha, (Koch, 1999), and Edmund Gabory (†1814),<sup>3</sup> trained by Ramsden in London. In 1801, Repsold constructed a transit instrument (8-ft = 2.60-m focal length, vertical circle  $3\frac{1}{2}$ ft = 114-cm, reading accuracy approximately 5 arcsec). Such meridian instruments allow the exact determination of time by observing a star transit through the meridian (the south-zenith-north line). The time and elevation angle of the stars are measured when they culminate — reach the highest point in the meridian. Repsold used it for observing together with Horner and Heinrich Wilhelm Matthias Olbers (1758-1840), astronomer and physician in Bremen:

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<sup>1</sup> For more information see (Koch, 2001, p. 82-190, 255-296; Koch, 2003; Koch, 2010; Schramm, 2010; Repsold, J. A. 1896).

<sup>2</sup> In 1799, he married Margaretha Eleonore Scharf (1780-1854), the eldest daughter of his predecessor. (Repsold, J. A. 1915, p. 21).

<sup>3</sup> Gabory started an optical and mechanical workshop for scientific instruments near St. Nicolai church (*Neue Burg* 14) in Hamburg in 1796 (Koch, 2001); his activities came to a sudden end during the French occupation. His children Edmund Nicolas und Mary Ann (1795-1858) took over the workshop; in 1823, Mary Ann married the marine instrument maker and dealer Andres Krüss (1791-1848). Cf. (Wolfschmidt, 2013b, p. 27-28).

Herr Repsold has made a small transit instrument, eight inches in length, which gives very precise determinations of time. On the night of October 2nd to 3rd, when it was carefully adjusted by a very sensitive level\*, stars of low and high ascension, which Dr. Horner and Repsold observed, gave always the same result, the time precise to  $\frac{1}{2}$  second. [...] There is now hope that the longitude of Hamburg will be eventually precisely determined; previously it was impossible because of the uncertainty in time keeping. Repsold competes with the first English artists. [...] Olbers, who was with us for a few days, took great pleasure in this excellent work.<sup>4</sup>

In 1803, Horner made use of a Repsold transit instrument on his circumnavigation of the world with *Krusenstern* (Repsold, J. A. 1915, p. 23).

200 years after Rømer, a remarkable breakthrough took place — the first modern meridian circle was constructed in 1802/03 by Johann Georg Repsold — perhaps based on a suggestion by Horner and/or by Gabory, both had contacts to Copenhagen (Herbst, 1996, p. 161-164). But whether Repsold was familiar with Rømer's instruments cannot be determined with certainty. In any case, Repsold's innovative instrument is a very free and considerably improved instrument compared to the *Rota Meridiana*, and in addition combined with the idea of the repeating circle. Carl Friedrich Gauß (1777-1855), who knows for sure and experienced using it, wrote in (Gauss, 1819, p. 56): “qu'il [le cercle de Repsold] a été construit sur les idées tout-à-fait neuves et originales de l'incomparable artiste.”

Repsold had also polished the lenses for his meridian circle himself, because the English glass, which he wanted to use, was inadequate and difficult to get during the *Continental Blockade*. He improved his crown and flint glass for achromatic objectives by calculations of the refraction index with the help of Gauß (letter, September 24, 1809) (Koch, 2000b, p. 11-13). But he stopped these experiments later, because he couldn't reach Fraunhofer's quality. This meridian circle (10.4-cm objective, 2.20-m focal length, 1.10-m diameter of the circle, 1.3-m horizontal pivot axis, 2.40-m length of the instrument) had first light in 1803. In addition, he used a pendulum clock, made by himself with a special compensation pendulum. In 1810, Repsold's

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<sup>4</sup> *Gilbert's Annalen*, vol. 9 (1801), p. 373-374, translated from German by the author.



pendulum clock was acquired by Friedrich Wilhelm Bessel (1784-1846) for the Königsberg Observatory.<sup>5</sup>

The meridian circle was used in Repsold's small observatory, a half-timbered house with a sliding roof, on Bastion *Albertus* (today *Stintfang*) of the Hamburg Baroque fortifications. Besides a guardhouse, a tea room for his wife was set up, surrounded by a small garden. Repsold's first observatory was a hexagonal building with a meridian slit and a pyramidal roof.<sup>6</sup> Heinrich Christian Schumacher (1780-1850), director of the Altona Observatory since 1823, was trained by Repsold in observing since 1808. (Koch, 2000b) Schumacher analysed Repsold's observations and comments: "In general, if you reduce the observations in Repsold's journals [logbooks], you don't know whether the excellence of the instrument or the skill of the observer should be more admired."<sup>7</sup>

With Napoleon's erection of the "United Departments of the Elbe and Weser Estuaries"<sup>8</sup> (1811-1814), Repsold's first observatory had to be demolished in 1813. The wood of the building was used to warm his house this winter. Already in 1812, Repsold brought the instruments to his home. Schumacher had compiled a "Liste des instruments de l'observatoire de M. Repsold" with attached values (1812). Schumacher's manuscript provides information; it was probably written down as a reference for possible compensation: "Un instrument de passages de 8 piés avec un circle de 4 piés qui donne immédiatement la seconde, fait par M. Repsold, Cary circle de répétition, Dollond sextant, l'horloge à pendule, Barraud chronometer, trois télescopes de 8, 6, et  $2\frac{1}{2}$  ft distance focale avec pieds", and smaller instruments; the value of the collection is estimated at 20,000 francs.<sup>9</sup>

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<sup>5</sup> Letter from Repsold to Bessel, June 5, 1810, (Bessel, 1848, p. 6-7).

<sup>6</sup> Observatory, financed by the Admiralty of Hamburg (11.3.1802), construction subsidy 800 Courant Mark and loan 1500 Courant Mark. Cf. (Meeder, 1838).

<sup>7</sup> "Aus einem Schreiben des Prof. Schumacher: Überhaupt weiß man, wenn man aus Repsolds Journalen rechnet, nicht, ob man die Trefflichkeit des Instrumentes oder die Geschicklichkeit des Beobachters mehr bewundern soll." (Schumacher, 1810, p. 503).

<sup>8</sup> *Vereinigte Departements der Elbe- und Weser-Mündungen*.

<sup>9</sup> The complete list of his instruments (with value indication) in the Albertus Observatory in 1812, besides the main instrument, the meridian circle, e.g. 8 ft transit instrument, Cary 1 ft repetition circle, Dollond 7-inch sextant, a compensated

Repsold's workshop was supervised by his friend Johann Arnold Libbertz (1769-1850s), when his own mechanical engineering workshop allowed it.<sup>10</sup> At that time, Repsold employed 7 workers, "3 fairly skilled and 4 for the execution of rough work" (Repsold to Horner, April 15, 1821).<sup>11</sup>

In spite of Repsold's professional duties as head of the Hamburg fire brigade (especially in the time of Napoleonic occupation), he succeeded to construct besides the meridian circle (Repsold, J. A. 1908) several instruments, e. g. a universal instrument with a 10-inch horizontal and 13-inch vertical circle (1806), an 11-cm transit instrument (1829), used in *Millerntor* Observatory — today in the *Astronomical-Physical Cabinet* in Kassel. In 1806/25, he built a length dividing machine, which is preserved in the *Deutsches Museum* in Munich.<sup>12</sup> In addition, he was engaged with the making of the different surveying instruments for Schumacher and Gauß. There was an intensive interaction between science and astro-technology (Herbst, 1996, p. 215-219), between ideas or needs of the scientists like Gauß, Bessel and Schumacher on one side and Repsold as instrument maker on the other side. Essential for Repsold's precision instrument making was the construction of a circle dividing machine of 2 ft (1818). For J. G. Repsold's circle dividing machine, an extra pavilion was erected next to the observatory. He started a larger circle dividing machine of  $4\frac{1}{2}$  ft (1819/21 to 1830), the division in arcsec was difficult, especially because he had to work at home in a dark room; later it was finished by his son Adolf Repsold (1806-1871) (Repsold, J. A. 1914) in 1835.<sup>13</sup> Due to this problem, J. G. Repsold could not deliver

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pendulum clock, marine chronometer, made by Barraud of London, a counter, three achromatic telescopes of 8 ft, 6 ft, and  $2\frac{1}{2}$  ft focal length, barometer, thermometer, and a comet seeker, can be found in Hamburg State Archive HH 622-1, 7, cf. reprinted in German in (Koch, 2001, p. 205).

<sup>10</sup> Libbertz's workshop was *Rödingsmarkt* 57, where he built the machine for the first Elbe steamer *Patriot*.

<sup>11</sup> (Repsold, J. A. 1915, p. 40), cf. (Koch, 1999, p. 97-98).

<sup>12</sup> Inv.-Nr. 2550, Image Nr. BN 01562. Also his lathe for precision instrument making is preserved, Inv.-Nr. 47930.

<sup>13</sup> Large  $4\frac{1}{2}$  ft circle dividing machine (1835), photo around 1900, *Hamburg State Archive*, HH 621-1, A III 2a. This machine was destroyed because — at that time — no museum wanted to have it. For more information see (Koch, 2001, p. 191-254).

quickly more meridian circles to Schumacher, Bessel, and to Sweden, (Koch, 2001, p. 228) and he had to recommend to buy it from Reichenbach or Ertel.

Tableau 1 - Instruments made by Johann Georg Repsold

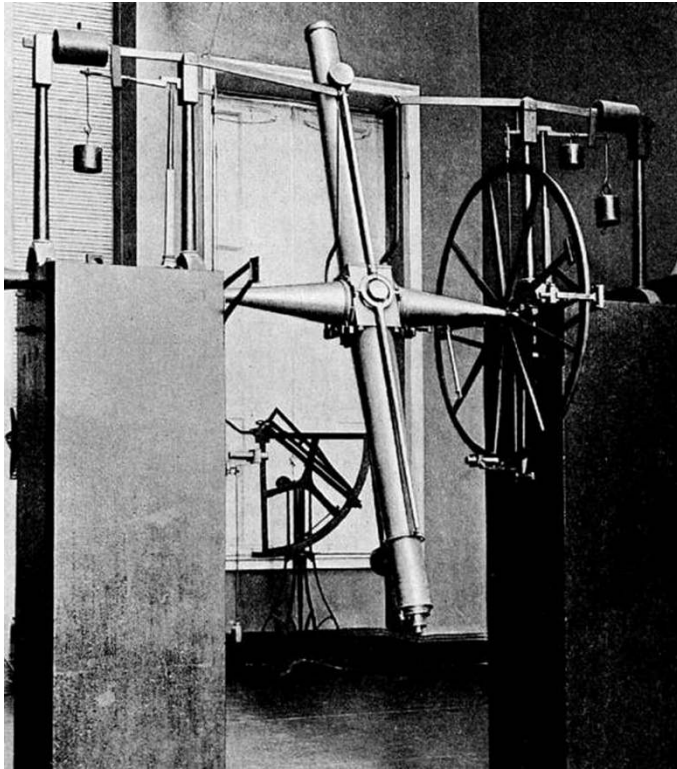
<i>Year</i>	<i>Instrument</i>	<i>Observatory / Customer</i>
1801	Small transit instrument	Repsold's home
1803	Meridian circle	Repsold Observatory (1802)
1803	Transit instrument	Johann Caspar Horner (Zürich)
1806	Universal instrument	J.G. Repsold
1810	Light apparatus	Lighthouse <i>Neuwerk</i> , Elbe estuary
1814	Pendulum clock	Königsberg Observatory, Bessel
1817	Transit instrument 24-inch	Altona Observatory, H.C. Schumacher
1818	improved Meridian circle	Göttingen Observatory, C. F. Gauß
1818	Circle dividing machine	J.G. Repsold
1820	Basis apparatus	Braaker Basis, H.C. Schumacher
1821	Heliotrop	Göttingen Observatory, C. F. Gauß
1821	Small transit instrument	Peter Andreas Hansen (1795-1874), Helgoland Observatory (1824)
1825	Length dividing machine	J.G. Repsold, Deutsches Museum
1825	Pendulum apparatus	Königsberg Observatory, Bessel
1826	Transit instrument 5 ft	Millerntor Observatory
1828	Lighthouse apparatus	Lightvessel Kattegat
1829	Transit instrument 5 ft	Millerntor Observatory (now in Kassel)
1827/31	Transit circle	Carlton Hill Observatory Edinburgh (16cm)
1818/35	4 $\frac{1}{2}$ ft circle dividing machine	J.G. Repsold and son Adolf

In 1818, Repsold restored his first meridian circle and improved it by adding reading microscopes, changing the previous division points to division lines, and sold for 1300 *Taler* to Carl Friedrich Gauß, director of Göttingen Observatory.<sup>14</sup> The meridian circle (Fig. 1) was delivered and

<sup>14</sup> (Grosser, 1998). Cf. *Sammlung historischer Gegenstände am Institut für Astrophysik* — University Collections of the Institute of Astrophysics, University of Göttingen, the vertical measuring circle, the 9-spoke wheel with a diameter of 115-cm, is still existing, Inv.-Nr. A332, as well as a reading microscope for determining the elevation angle, and two eyepieces, cf. seven photos in (Koch, 2001, p. 221-225). Bessel was also interested to buy this meridian circle, but he was later than Gauß in requesting for it.

mounted by Repsold himself in Göttingen; it was placed in the Eastern meridian hall on massive pillars, and was in use until 1926. Especially Karl Ludwig Harding (1765-1834) measured with this meridian circle zenith distances and transit times of stars as they pass through the meridian in order to compile his *Atlas novus coelestis* with 120,000 stars on 27 plates, observed since 1808 (Harding, 1822). In 1926, the meridian circle was dismantled in the course of the dissolution of the meridian hall.

Figure 1 - First Meridian circle, Johann Georg Repsold (1803)



Since 1818 Göttingen, used until 1926, photo around 1900. Source: (Repsold, J. A. 1908, Fig. 155), reproduced from (Ambronn, 1899, vol. 1, Fig. 917)

Repsold's innovative elements of his meridian circle were the following: he constructed high-precision spirit levels in order to control the inclination of the axis, controlled the direction by two collimators, and

introduced reading microscopes — instead of the nonius — for the vertical circles. But Repsold could not enjoy the success of his invention, like Schumacher wrote, that “Repsold could not realize the possibilities of his meridian circle.”<sup>15</sup>

In 1828, two years before his death, Repsold’s experimented to construct a “tape chronograph\*” in order to improve the measuring of the star transits: “Instead of the eye-ear method with the beats of the clock — Repsold manufactured an apparatus, essentially a clockwork, that moves a strip of paper between two rollers, and above it a pusher for the finger with which you can snap a fine point of a needle against the paper. With this, first, the seconds of the pendulum clock should be recorded on the paper, and second, for each star transit, the time is marked with one stitch. Finally, the times of the transits can be measured between the seconds, assuming that the paper strip continues to move uniformly. This is definitely a precursor of the later chronographs for astronomical observations.”<sup>16</sup>

In 1866, Matthäus Hipp (1813-1893), Neuchâtel, together with Frédéric-William Dubois (1811-1869), developed an electrical tape chronograph with a chronometer for exact time registration of star transits.<sup>17</sup> The transit time recorded on a tape moving with a few cm/s can be determined with an accuracy of 0.01 seconds. Since 1889, Hipp handed over the company to the engineers Albert Favarger and A. de Peyer, which continued as *Peyer & Favarger, Succ. de M. Hipp* until 1908. The modern printing chronograph was developed around 1960. It no longer prints the recorded time on a strip of paper or wax paper, but in digital form using radio time signals. The accuracy of the time registration is in the range of a few milliseconds. It was made for observatories by the Swiss firm FAVAG, also used in Hamburg.

Johann Georg Repsold was in contact with the Munich instrument makers, he travelled with his eldest 14 years old son Georg Repsold (1804-1867) via Gotha, where he visited Johann Franz Encke (1791-1865), Marburg and Nuremberg to Munich. There he visited the workshop of Reichenbach in 1818, also Reichenbach’s facilities in Benedictbeuren, Reichenhall

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<sup>15</sup> “Repsold die Möglichkeiten seines Meridiankreises nicht ausschöpfen könne.” Letter from Schumacher (October 23, 1810) to Franz Xaver von Zach (1754-1832), published in (Schumacher, 1810, p. 499).

<sup>16</sup> (Repsold, J. A. 1915, p. 49), translated from German by the author.

<sup>17</sup> (Kahlert, 1987, p. 22 f.; Ramsayer, 1970, §36 Zeitregistrierung).

and Berchtesgaden, the workshops of Utzschneider and Ertel in Munich, and then Horner in Zürich. On the way back he travelled via Frankfurt, Cassel, and again Göttingen. Probably as a result of his stay in Munich, Repsold was appointed an honorary member by the *Polytechnic Association of the Kingdom of Bavaria* on September 9, 1819 “as evidence of the recognition of excellent services to the promotion of the arts and trade” (Repsold, J. A. 1915, p. 37). In addition, Repsold travelled, accompanied by Schumacher, to France and England in 1819. In 1826, Repsold made a second trip to Munich via Gotha, Nürnberg, München, Zürich, and back via Heidelberg, Köln (Repsold, J. A. 1915, p. 48). By these journeys, Repsold got inspiration and impetus for his work (and vice versa), but Repsold also spread his ideas about the meridian circle, which surpassed the circle instruments at about this time. “Reichenbach has now essentially adopted Repsold’s idea for the construction of meridian instruments and combined the transit instrument and the vertical circle [the construction of the meridian circle from 1802].”<sup>18</sup>

Bessel’s comparative judgment of English and German instrument makers is of interest, is published in the *Populäre Vorlesungen* (Popular Lectures) in 1848:

These were Reichenbach in Munich and Repsold in Hamburg, both of excellent talents and endowed with the courage that is necessary to start something new in a country where all preparations are still lacking. Reichenbach, who had tackled every branch of precision mechanics with the fire of his youth, who built pipes for the salt works in Bavaria with the same success that he had already achieved with astronomical instruments, soon he increased manufacturing on a large scale and provided all of the observatories and astronomers from his workshop in Munich with instruments which surpassed by far the English instruments. Repsold, who was more concerned with producing the highest perfection than delivering many instruments, had for this reason gained less influence on the observatories; but his perfect art has left admirable

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<sup>18</sup> “Reichenbach hat jetzt für die Konstruktion von Meridianinstrumenten im wesentlichen die Repsoldsche Idee angenommen und Mittagsfernrohr und Höhenkreis vereinigt [die Bauart des Kreises von 1802].” Letter from Bernhard August von Lindenau (1779-1854), Gotha, to J. C. Horner, Zürich, November 20, 1816. Quoted after (Wolf, 1875, p. 495).

works to a few close friends, and he even supplied England with a main instrument, in spite of national pride and large import duty.<sup>19</sup>

The next famous meridian circles after Repsold 1802/1918 were designed by Georg Friedrich von Reichenbach (1771-1826) of Munich:<sup>20</sup> for Naples Observatory in 1814 (5 ft focal length), for Göttingen and Königsberg in 1819, for Bogenhausen Observatory in Munich (6 ft focal length), for Tartu Observatory (Struve) Reichenbach & Ertel in 1822, and one for the Seeberg Observatory in Gotha of Franz Xaver von Zach (1754-1832) in 1825.<sup>21</sup> Reichenbach used a circle dividing machine of 50 Paris inches (135-cm) diameter for dividing the scales on the circles, and improved the accuracy of reading from one to one third of an arcsec or the reading of the declination\* by a factor of 10. But Reichenbach did not want to detach himself from the English vernier scale (nonius) in astronomical instruments and to introduce reading microscopes or the micrometer screw. Meridian circles were ordered from Reichenbach (partly including Utzschneider, Ertel or Starke) in the following observatories in middle and Eastern Europe and Italy: Naples (1814), Munich, Kingdom of Bavaria (1819), Königsberg in Prussia (1819), Göttingen, Kingdom of Hanover (1819), Turin (1820), Ofen/Budapest, Austrian Empire/ Hungary (circa 1820), Dorpat/Tartu, Tsardom of Russia/Estonia (1822), Altona, Denmark (1867 Prussia, German Empire, Hamburg) (1823), Helsingborg/Helsinki, Tsardom of Russia/Finnland (1825), Gotha, Duchy of Saxe-Gotha-Altenburg (1826), Speyer, Bavarian Palatinate (1826), Warschau/Warsaw, Poland (1826), Modena (1827), Cracow (circa 1829), Vienna (1830), Oslo, Norway (1833), Milan (1834) (Herbst, 1996, p. 209-210).

In Christiana (today Oslo) Observatory, Christopher Hansteen (1784-1873) also ordered the meridian circle from Ertel in Munich (1826)

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<sup>19</sup> (Bessel, 1848, p. 30), translated from German by the author.

<sup>20</sup> The Mathematical-Mechanical Institute Utzschneider, Reichenbach, Liebherr in Munich was founded in 1804. (Repsold, J. A. 1908) Since 1821, Traugott Leberecht von Ertel (1778-1858) took over the precision engineering workshop, and since 1834, it was renamed as T. Ertel & Sohn.

<sup>21</sup> For Stockholm Observatory, the meridian circle was delivered by Ertel of Munich (1830).

through the assistance of Schumacher. It was installed in the meridian room in the east wing.

The Norwegian National Assembly funded a 3-year instrument grant in the autumn session that year. At the time, Ertel was producing a meridian instrument for Stockholm. Schumacher somehow persuaded him to sell it to Christiania and when half the price was paid in advance by Hansteen, the matter was settled. (Enebakk & Pettersen, 2009, p. 260-273)

The meridian circle left Ertel's workshop in February 1828 and arrived in Hamburg about a month later. There it had to wait for a shipping opportunity to Christiania. Because Hansteen was participating in the Siberian geomagnetic expedition, the instrument was stored. Finally, it was assembled and mounted in the meridian room in 1834. The objective, made by Fraunhofer, had a focal length of 163-cm; for observations usually a magnification of 180 was used. "The 3-ft vertical circle [diameter 94-cm] was divided to 3' and could be read directly to 2'' using 4 verniers and 2 microscopes. On a separate pillar in the meridian room a pendulum clock by Urban Jürgensen in Copenhagen was mounted and regulated to show sidereal time\*" (Enebakk & Pettersen, 2009, p. 260-273), delivered in 1826, replaced by the pendulum clock, No. 1365, by Johann Heinrich Kessels in Altona in 1841. "A meridian marker was put up on the island Lindøya in the Christiania Fjord, 2,7-km due south of the observatory. [...] A collimator arrived that summer [1844] from Repsold to monitor any deviations of the telescope optical axis away from the meridian." (Enebakk & Pettersen, 2009, p. 260-273)

### **3. The Meridian Circles of A. & G. Repsold, 1830-1867**

In this paragraph, the new Repsold Observatory with Navigation School at Millerntor (1825) including the instrumentation is presented. After the death of Johann Georg Repsold in 1830, the workshop was renamed by his sons Georg & Adolf Repsold. A second generation of meridian circles was produced in the years 1830-1867, following the Hamburg prototype, installed in 1836 in Millerntor Observatory. The director Carl Rümker produced a famous star catalogue with it (published from 1843 to 1852). The Repsold company supplied observatories in Europe including Moscow and Kazan, Russia, in addition one in Georgia, Asia, and one in the USA — the international importance started.



Repsold has been repeating his request since 1821 to build a new observatory and enclosed plans to combine the observatory with a new building for the navigation school, cf. the long application text (Koch, 2001, p. 230-231). Finally he succeeded,<sup>22</sup> and the Millerntor Observatory with Navigation School was built on Bastion *Henricus* by Hinrich Anton Christian Koch (1758-1840) in 1825 with the help of a donation from a private foundation, the estate of the amateur astronomer J.C. Grell (June 7, 1822) (Wolfschmidt, 2013b, p. 26-27). The observatory had two cylindrical domes with conic roof and two meridian slits. The instruments were provided by Repsold — privately financed (July 30, 1823) (see Table 2)

Table 2 - Instruments of Johann Georg Repsold for Millerntor Observatory

<i>N°</i>	<i>Instrument</i>	<i>Price</i>
1	Meridian circle, 4 ft 3-inch, with 6 ft telescope	Mk. 6500
2	Transit instrument, 6 ft	Mk. 3500
3	Parallactic instrument with 2 ft circles, 4 ft telescope	Mk. 3200
4	Repetition circle, 21-inch, 2 $\frac{1}{2}$ ft telescope	Mk. 3000
5	Several telescopes of different focal length	Mk. 3000
6	Two pendulum clocks à 1000 Mk.	Mk. 2000

After Johann Georg Repsold's death in 1830, a — still existing — monument was erected in front of the Millerntor Observatory in 1833 (Suhr, 1833). Also in 1833, the observatory became Hamburg State Institute. The instruments had to be bought from the Repsold family; finally, Hamburg merchants, the *Verein der nach Archangel(sk) handelnden Kaufleute*, donated 32.000 MkBco (Hamburg BancoMark) for the acquisition.

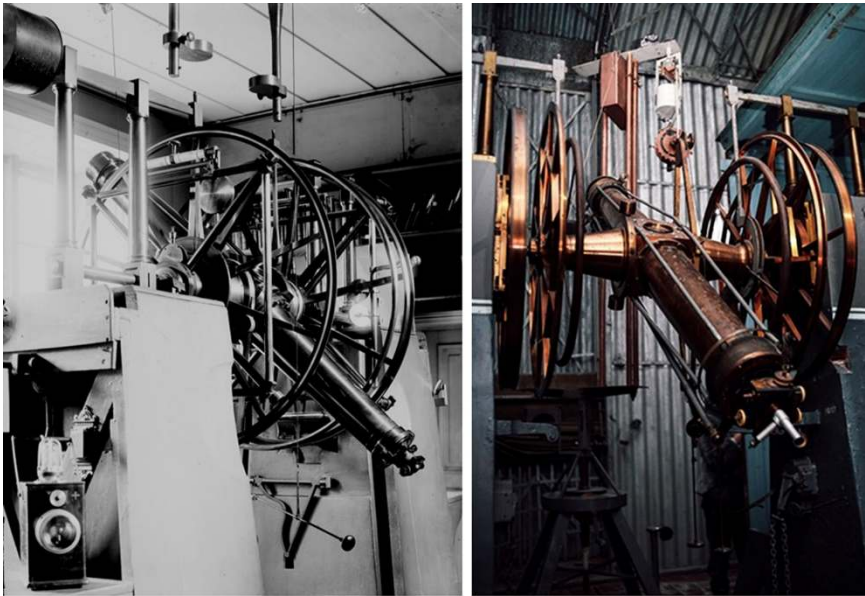
The Repsold workshop, led by the sons of Johann Georg Repsold, named Georg Repsold (1804-1867) and Adolf Repsold (1806-1871), had an emerging development. It remained first in *Herrengarten* in the fire brigade building, then from 1854 to 1871 it was transferred to *Böhmkenstrasse* near Michaelis in the Baroque city.

<sup>22</sup> Senatsbeschluß May 12 and 30, 1924; Hamburg State Archive HH Cl. VII, Lit H<sup>c</sup>, Nr. 1, Vol. 28, Fasc. 1.

In the 19th century, following Johann Georg Repsold, and a little bit later Reichenbach, the meridian circle and the transit instrument became a standard equipment of observatories.

A new 11-cm meridian circle (Fig. 2 left) with 103-cm diameter of the measuring circles, made by A. & G. Repsold of Hamburg (1833-1836), was installed in 1836 in the *Millerntor Observatory and Navigation School*, (Repsold G. & Repsold A., 1838, n°349, p. 226, Fig. 214b) an improved version with four reading micrometers on each side of the East-West pillars (Repsold G. & Repsold A., 1838, Fig. 213).

Figure 2 - Meridian Circles of Hamburg and Kazan Observatories,  
Adolf & Georg Repsold, Hamburg (1836 and 1845)



Source: Archive Hamburg Observatory (left); © photo by the author (right)

The main user of this instrument was Carl Ludwig Christian Rümker (1788-1862), who produced with this meridian circle his famous star catalogue (*Carl Rümkers Sternverzeichnis 1845.0*), observed between 1836 and 1856, with 17,724 exact stellar positions, published in several editions from 1843 to 1852 (Rümker C., 1852), the early date of these stellar observations renders them of value for the determination of proper motion. Richard

Schorr (1867-1951) started his career in Hamburg with meridian circle observations in 1899/1900; the result was a catalogue of 344 stars (Schorr, 1902). In the early years in Bergedorf Observatory, he made a valuable reduction of Rümker's catalogue (Schorr, 1922; Stephani, 2014, p. 190-192). The meridian circle of 1836 was used until 1907, and not mounted again in the new Bergedorf Observatory. Only the transit instrument (1829) was installed for timekeeping in a new transit building in Bergedorf (Schorr, 1910).

The firm of Repsold & Sons was for a number of years eclipsed by that of Pistor & Martins in Berlin, who furnished various observatories with first-class instruments. In 1838, the new Berlin University Observatory got a meridian circle, made by Carl P. H. Pistor (1778-1847) of Berlin, and a chronometer, made by Friedrich Tiede of Berlin. Following the death of Carl O. A. Martins (1816-1871), the Repsolds again took the leadership in the making of meridian circles.

The meridian circle for Bonn Observatory was made by Pistor & Martins in 1843. Friedrich Wilhelm August Argelander (1799-1875) studied in 1817 at the University of Königsberg (today Kaliningrad, Russia), especially trained by Friedrich Wilhelm Bessel (1784-1846) (PhD in 1822). Finally, in 1836, Argelander was appointed as full professor at the Friedrich-Wilhelms-University in Bonn, which was founded in 1818. Here he observed with this Pistor & Martins meridian circle in the eastern meridian hall (11.7-cm lens and 1.95-cm focal length), optics: Merz & Mahler of Munich. In the 50 years of use, 130,000 observations were made. The old meridian circle was moved to the western meridian hall and was replaced by a new meridian circle of 6 ft focal length in the eastern meridian hall, made by Repsold & Söhne in 1893 (Wolfschmidt, 2020a, p. 18-22). This was used for extensive stellar catalogues by Friedrich Küstner (1856-1936), and was in use until the middle of the 20th century. Finally, in 1862, the United States Naval Observatory, Washington, DC, installed a Pistor & Martins meridian circle.

In Great Britain and France (except in Strasbourg), no meridian circles of German makers were used. In 1851, George Biddell Airy (1801-1892) designed and installed a large transit circle of 20.3-cm (8-inch) aperture and 3.5-m focal length for the Royal Observatory Greenwich, optics by Troughton & Simms of London, mounting by Ransomes & May of Ipswich, optics

by Troughton & Simms of London,<sup>23</sup> used until 1954. The first Paris meridian circle was made by Gambey already in 1827, but the breakthrough was also after the middle of the 19th century. Urban Le Verrier (1811-1877), director of the Obervatoire de Paris 1854/70 and 1873/77, installed a large transit circle of 22.5-cm aperture in 1863, made by Secretan & Eichens, and a 19-cm meridian circle in 1878.

Table 3 - 10 Meridan circles, made by Adolf & Georg Repsold, 1830-1867

<i>Year</i>	<i>Observatory</i>
1835	Dorpat Observatory, Russia (Tartu, Estonia)
1836	Millerntor Observatory Hamburg
1839/41	Pulkovo Observatory, St. Petersburg, Russia (14.8cm) since 1955 Mykolayiv/Nikolaev Observatory, Ukraine
1841	Königsberg Observatory, Prussia (Kaliningrad, Russia) (15cm)
1843/46	Moscow Lomonosov University, Sternberg Astr. Inst., Russia (15cm) 1981 to GAISH in Maidanak, Uzbekistan
1845	Kazan Observatory of Kazan Federal University, Russia (Fig. 2 right)
1850	US Naval Academy (USNA), Annapolis, Maryland 1897 to US Naval Observatory (USNO) Washington, DC
1854	Madrid Observatory, Spain (16cm, 2.11m)
1862	Tbilisi/Tiflis Observatory, Georgia

The meridian circles of Adolf & Georg Repsold were supplied with Fraunhofer (Edinburgh) and mostly Merz objectives, (Kost, 2015) — later, in the time of Adolf Repsold & Sons, with Steinheil of Munich, and in the USA with Alvan Clark & Sons of Cambridge port, Massachusetts.

#### 4. The Meridian Circles of Adolf Repsold & Sons, 1867-1919

The third generation of meridian circles was produced by the company Adolf Repsold & Sons in the years 1867 to 1919. The prototype in Hamburg with all the innovative technical details is described, including the impersonal micrometer, and the sophisticated meridian building together with the mire house (1909). The catalogues of the *Astronomical Society* AGK 2 and AGK 3, created in international cooperation under the leadership of Hamburg, represent an important database for astronomy and celestial mechanics. An

<sup>23</sup> This Airy Meridian was adopted as the Prime Meridian of the World in 1884.

outstanding important market became Middle and South America, especially Argentina, but also besides Europe, meridian circles were delivered to the USA, and Asia.

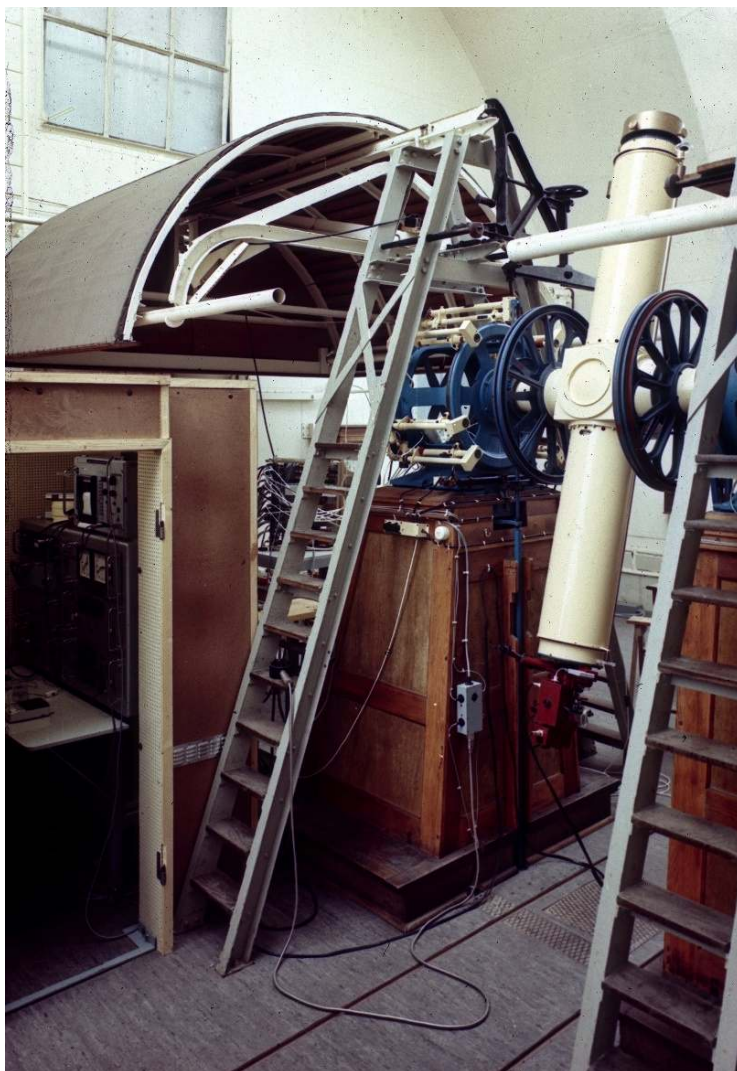
The Adolf Repsold & Sons workshop, led by Adolf Repsold (1806-1871) and his sons, named Dr.phil.h.c. Johann Adolph [Hans] Repsold (1838-1919) and Oscar Philipp Repsold (1842-1919), remained from 1854 to 1871 in *Böhmkenstrasse*, then, from 1872 to 1919, it was transferred to *Borgfelder Mittelweg* near *Berliner Tor* (today *Klaus-Groth-Straße*). (Repsold, J. A. 1914), (Repsold, J. A. 1915) The important purpose of meridian circles was the determination of exact stellar positions, right ascension and declination. Already, the precursor observatory had started a tradition of elaborating stellar catalogues (*Carl Rümkers Sternverzeichniss*) (Rümker C., 1852). The Hamburg Observatory in Bergedorf continued this tradition by participating, on several occasions in the course of the 20th century, in major collaborations to draw up new editions of stellar catalogues.

The Large Hamburg Meridian Circle (Fig. 3) for the new Hamburg Observatory in Hamburg-Bergedorf, a high-precision instrument with large divided circles of 74-cm diameter each was manufactured by the company of Adolf Repsold & Söhne (1909). It was equipped with optics made by C. A. Steinheil & Söhne of Munich: a 19-cm diameter lens with a focal length of 2.30-m. The materials for this instrument have been carefully coordinated (Schorr, 1906). The glasses and metals were selected in such a way that the expansion behavior of all materials harmonized with changing temperature conditions. Nickel steel and iron were chosen for the instrument, which was much more rigid than brass, and for the achromatic lens borosilicate glass (Schott O. 3453) and flint glass (Schott O. 118).

Greatest care had to be paid to the monitoring of the telescope bearings in order to be able to measure star positions with the instrument with the highest possible precision. Massive stone piers which supported the instrument, prevent transmission of vibration from the building to the telescope. The flexure in the horizontal position of the tube was determined by two collimators. Certain instrumental errors could be averaged out by reversing the telescope on its mounting with the help of a carriage\*. Several control water spirit levels were installed, and the reading took place over very large graduated circles of 74-cm in diameter. The limb has a graduation of 4 arc minutes line spacing, made of silver in the first circle and an alloy of platinum

and palladium in the second circle, which has almost the same coefficient of expansion as iron.

Figure 3 - 19-cm Meridian circle, A. Repsold & Sons of Hamburg (1909)  
for the new Hamburg Observatory in Bergedorf



Source: Archive Hamburg Observatory

This meridian instrument marks the end of one hundred years of evolution in meridian circles. These sophisticated instruments have been ordered from all over the world.

This meridian circle had an impersonal micrometer, invented by Johann Adolf Repsold (Kowalski, 1897), which significantly increased the performance of the meridian instruments. Such an impersonal micrometer (together with a declination micrometer) is used to reduce systematic observational errors. In the focal plane of a meridian circle, a vertical wire is mounted, which can be moved across the field of view to follow a star. In addition, there is an instrumentation to record the position of the wire as a function of time by photographic (later by photoelectric) methods since 1920s and 1960s respectively.

Closely connected to the mounting of the meridian circle is the specialized building. In Hamburg, the meridian circle building (8m × 10m) was placed on the highest elevation of the observatory grounds. The half cylindrical roof of the observation room (similar to Cape town, Kiel, and Kremsmünster, 1906) rests on a plastered brick base; with the help of two sliding shutters, the half barrel-shaped roof can be opened up to a width of three metres (Wolfschmidt & al., 2001, p. 38).

The roof consists of double metal layers with a gap in between. There are ventilation holes in the top and lower metal layer that allow for the free circulation of air. This air flow is further enhanced by the use of electrical ventilators and has the effect of ensuring that the air inside the observation room has nearly the same temperature as the air outside. To eliminate temperature differences caused by direct solar radiation as much as possible, in the original design a wooden shutter-like panelling construction resembling sun blinds was mounted on the outer metal layer at a distance of 6-cm. However, this construction did not prove to live up to its intended purpose and was quickly taken down again. (Hünsch, Seemann & Wolfschmidt, 2012)

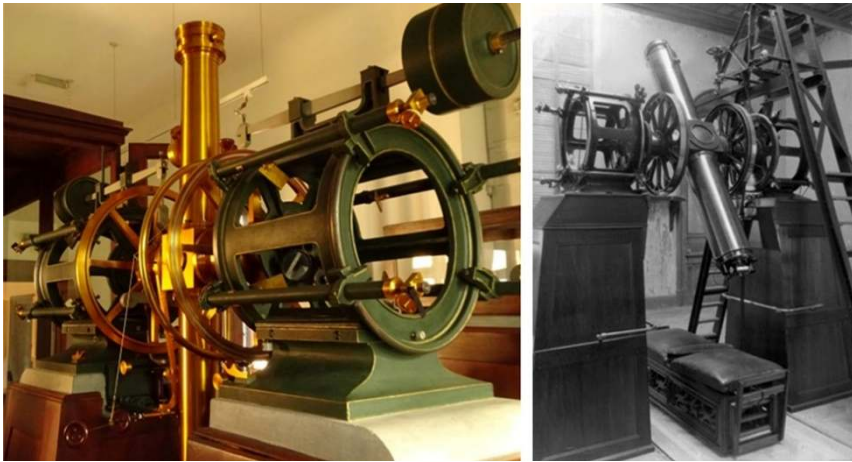
In addition, a mire house (house of the calibration azimuth mark, called 'mire') was built exactly to the north of the meridian building and in a distance of 105-m. It has the shape of a rectangle and its outside is panelled with wood. The meridian circle can only be moved along one axis so that the instrument is pivotable in the north-south direction, namely in the meridian which is why the foundation had to be very stable and precise. This was

regularly checked from the distance with the help of calibration marks. This mire also forms the south mire for the Repsold's old 4-inch transit instrument to be set up in exactly the same meridian 53-m further north.

Adolf Repsold & Sons made identical meridian circles for La Plata, Córdoba, Santiago de Chile, Porto Alegre (Brazil), and Hamburg-Bergedorf observatories.

In 1906, Dr. Francesco Porro di Somenzi (1861-1937), Director of the Observatory and first Dean of the Faculty of the Mathematical, Physical, and Astronomical Sciences, (Minniti Morgan, 2011) acquired a collection of new instruments: a large meridian circle (Fig. 4 right), made by A. Repsold & Söhne, a comet-seeker, made by Zeiss of Jena, two Repsold transit instruments, and zenith telescopes, made by Wanschaff of Berlin.

Figure 4 - Meridian Circles of Kuffner Observatory in Vienna and La Plata Observatory, Argentina, A. Repsold & Sons of Hamburg (1884 and 1906)



Source: © photo by the author (left), Archive Hamburg Observatory (right)

The meridian circle has a two-lens objective by Carl Zeiss of Jena, 19-cm of aperture and 2.8-m of focal length. It arrived in La Plata in May 1908. The Repsold meridian circle was in its original packaging during a quarter of century. In 1932, Johannes Franz Hartmann (1865-1936) of Göttingen, director from 1921 to 1934, visited the astrophysical station Bosque Alegre (under construction) and offered his instrument to Córdoba Astronomical Observatory — in order to be installed in Bosque Alegre (Paolantonio, 2012). In



1934, Ing. Félix Aguilar (1934-1943), new director from 1934 to 1943, specialist in geodesy, succeeded finally in getting back the Repsold instrument to La Plata, replacing the large Gautier meridian circle with Henry brothers optics (1887) in 1938, first light in 1940. In 1945, the Austral Félix Aguilar Astrometric Station in La Leona, Santa Cruz province, was erected (Paolantonio, 2012). The Repsold meridian circle was transported to this station in 1961, and was used until the late 1970s; the aim was measuring the positions of circumpolar stars. Today it is back in the La Plata Observatory museum.

The emphasis of the Argentine National Observatory Córdoba was the measurement of precise stellar positions, (Paolantonio & Minniti Morgan, 2009, p. 13-14) a 12.2-cm meridian circle, manufactured by Adolf & Georg Repsold of Hamburg (1868), was acquired in 1870, when the observatory was inaugurated. (Paolantonio, 2009a) Around 1900, the new director John Macon Thome (1843-1908) could acquire in 1907 a larger meridian circle (price 33,000 Mark), made by A. Repsold & Söhne, with a 19-cm objective diameter and 2.25-m focal length, optics from Steinheil of Munich (Paolantonio, 2009b). The instrument arrived in 1909.

The latest innovations were included for this instrument: tube made up of two symmetrical conical parts with a central cube-shaped sector that gave it great rigidity (the tube is covered by a separate bronze cylindrical tube to form an air chamber that insulated it thermally), inversion system that allowed to do it in a short period of time, an overhead mirror and improved counterweights. The material with which it was made was mainly steel and cast iron. The axis was located at a height of 2.1-m above ground level. (OAC Archive, S. Paolantonio; Paolantonio, 2009b)

Thome had died in 1908; the new director Charles Dillon Perrine (1867-1951) from Lick, director in Córdoba from 1909 to 1936, completed the meridian circle shelter building; first light was in 1910. According to Luis Guerin (1929), the instrument exceeded initial expectations:

The lens was made by Steinheil of Munich and it is a true masterpiece. You can easily separate doubles whose components are at 0.5", and as an interesting data on their quality, I will say that I have observed several times the companion of Sirius, which is a conclusive proof, if the reduced focal length is taken into account and that the companion of Sirius is of 9th magnitude and at the same time so close to the main one that for instruments the size of

the Meridian Circle it is almost always hidden in the rays of that splendid sun. (Minniti Morgan, 2010)

The meridian circle was successfully used in Córdoba for several decades until 1961.<sup>24</sup> A transfer to Félix Aguilar Astronomical Observatory (OFA) in the city of San Juan was decided in 1961, and the Benjamin Gould pavilion was built there. In 1966, the meridian circle was transferred to San Juan, and observations started in 1969, continuing until 1993 (Paolantonio, 2009b).<sup>25</sup> It produced the *First Fundamental Catalogue*, the southern areas of the first *Katalog der Astronomischen Gesellschaft* and the *Catálogo Círculo Meridiano de San Juan*.

The new Hamburg meridian circle (1909) was assigned to the observer Franz Dolberg (1876-1956), who even — before the move to Bergedorf — was working on a completely revised catalogue of 12,000 stellar positions, first observed by Charles Rümker in the years 1836-1855, (Rümker C., 1852) and now observed again. This work was done with the Repsold Equatorial, made by A. & G. Repsold in 1867, which was only suitable for relative measurements, and continued with the new meridian circle, with which the absolute measurements were carried out (Rümker G., 1885). Benno Messow (1876-1930), to whom the transit instrument was assigned, and who also worked on the meridian circle, played a key role in the publication of the catalogue (Dolberg, 1920). While most of the observatory's telescopes were idle during World War II, the meridian circle and the old transit instrument were working at full speed to provide the Air Force with star and planetary positions for navigation and, of course, for time keeping (the data were even calculated up to 1960 in advance). In addition, in 1937, Hamburg Observatory in Bergedorf received a small meridian circle with an aperture of 12.3-cm and a focal length of 1.5-m from Wilhelmshaven, made by A. Repsold & Sons (1875). Georg von Struve (1886-1933) had used it for his observations (*Beobachtungen von 562 Sternen am Meridiankreis in Wilhelmshaven*, 1922).<sup>26</sup>

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<sup>24</sup> Instead of astrometry, the era of astrophysics started.

<sup>25</sup> After the move of the meridian circle to San Juan, in 1970, the shelter in Córdoba was demolished.

<sup>26</sup> The Wilhelmshaven meridian circle is since 1954 in the *Institut für Angewandte Geodäsie*, Frankfurt University, Frankfurt am Main.

Already in 1869, the “Astronomical Society” *Astronomische Gesellschaft* (AG) initiated the AGK zone catalogues with 100,000 stars — a cooperation of 16 observatories all over the world.<sup>27</sup> This meridian circle astrometry program (1870-1887) was a very significant observational contribution to astronomy, and also its follow-up (1897-1907) to determine stellar proper motions. The first catalogue AGK 1 was published in 1908. For example, Carl Fredrik Fearnley (1818-1890), appointed as observing astronomer in Oslo Observatory in 1844, professor in 1865, participated in the AGK 1 programme, and published his work is *Zonenbeobachtungen der Sterne zwischen 64°50' und 70°10' nördlicher Declination* (1888). The Christiania AGK1 by Fearnley was followed up for proper motion studies by Hans Geelmuyden (1844-1920) and Jens Fredrik Wilhelm Schroeter (1857-1927). They reobserved 822 selected stars from the Christiania AGK1 and added 1774 fainter proper motion candidates. A total of 2596 stars in the Christiania zone were observed with an improved and upgraded meridian circle between 1897 and 1905, with additions in 1906-1907 (*Meridian-Beobachtungen von Sternen in der Zone 65°-70° nördlicher Declination*) was published in 1905 (Band 1) and 1912 (Band 2). This is a precursor to the AGK project to reobserve the entire set (as discussed in the following paragraph).

Fifty years after the AGK 1, Richard Schorr (1867-1951), director of Hamburg Observatory, and other astronomers proposed to start a second catalogue (decision at the AG conference in Leipzig in 1924), especially the proper motions were of interest. The catalogue of the *Astronomical Society* AGK 2 was created with less international cooperation<sup>28</sup> — only the Hamburg and Bonn observatories with Pulkovo, St. Petersburg, were active. The fundamental stars, pole stars and programme stars in right ascension and declination for determining the absolute coordinates were measured in a short

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<sup>27</sup> Kazan / Russia, Berlin, Christiana (Oslo) / Norway, Helsingfors (Helsinki) / Finland, Gotha, Harvard Cambridge / USA, Bonn, Chicago / USA, replaced by Lund / Sweden, Leiden / Netherlands, Leipzig, Albany (New York) / USA, Nikolajev / Ukraine, Straßburg, Vienna, Washington / USA, Algier (Algeria) / French-Northafrica, and La Plata and Córdoba, Argentina, for the Southern sky, cf. (Paolantonio, 2013).

<sup>28</sup> The final AGK 1 catalogue was inconsistent: Meridian circles from different makers were used during the 40 years of observing and analysis; the reading changed from the eye-to-ear method to chronograph use.

time period from 1928 to 1933 using modern, partially automated meridian circles with photographic registration. The AGK 2 was published in 1932 and in 1951/53 with 200,000 stars up to an accuracy of  $\pm 0.1''$ .<sup>29</sup> The elaboration of the AGK 3 was proposed by Hamburg Observatory, and was carried out — in cooperation with the observatories in Berlin-Babelsberg, Bordeaux, Greenwich, Heidelberg, Nikolajev (Ukraine), Ottawa, Paris, Pulkovo, Strasbourg, and Washington D.C. — during the 1950s and 1960s, published in 1975. The precise measurements of the AGK, made with astrographs in combination with meridian circles with photographic registration for the fundamental stars, represent an important database for astronomy, astrometry, and celestial mechanics.

For Kiel Observatory, the largest meridian circle was constructed by Repsold & Sons. The new meridian circle, ordered by Paul Harzer (1857-1932), was to have unusual dimensions (1898): focal length 3-m, lens diameter 20-cm, vertical circle diameter preferably over 1-m. In a word: Harzer wanted to have the largest and most efficient meridian circle in the German Empire (Lühning, 2009, p. 115-129). Repsold implemented the usual 4-arc minute division. In 1903, it got first light; but with this meridian circle serious problems had to be solved in order to get finally more or less convincing accuracy. The Repsold meridian circle (16-cm =  $6\frac{1}{2}$  finch), constructed for the Strasbourg Observatory, bought in 1876 (first light 1880), underwent improvements and redesigns thanks to Friedrich August Theodor Winnecke (1835-1897), and is to be regarded as the first type of modern meridian circles of the Repsold company — a large number of which were delivered to many observatories in Germany and abroad between 1878 and 1919. This serial production ensured comparable results, and the meridian circles were useful until the satellite astrometry.

In the table 4, you find the modern perfected meridian circles (third generation), made by Adolf Repsold & Söhne, 1868-1919; the instruments can be found all over Germany (7), Europe (11) and the USA (6), but also in Asia (3), Australia (1), Middle and South America (6).<sup>30</sup>

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<sup>29</sup> For more details see (Wolfschmidt, 2020b, p. 80-85).

<sup>30</sup> This table, like also table 3, Adolf & Georg Repsold, 1830-1868, is compiled from Hamburg State Archive HH 621-1 Firmenarchiv A. & G. Repsold, (Wolfschmidt, 2020; 2021; 2009; Repsold, J. A. 1914; Bartels et al., 1913).

Table 4 - 32 Meridan Circles, Made by Adolf Repsold &amp; Söhne 1867-1919

<i>Year</i>	<i>Observatory / Customer (aperture, focal length)</i>
1868	Dearborn Observatory, Chicago 1862, Illinois, USA (16.2cm, 1.83m) 1889 to Northwestern University, Evanston, Illinois, USA
1868	National Astronomical Observatory, Córdoba, Argentina (first light 1870)
1869/71	Capodimonte Observatory, Naples, Italy (first light 1874, 16.5cm, 2.02m)
1870	Kiev Observatory, Ukraine
1874	Lund Observatory, Sweden (15.7cm, 2.28m)
1874	Tashkent (1865-1991 Russian Empire, USSR), Uzbekistan (12cm)
1875	Wilhelmshaven, Germany, 1937 Hamburg-Bergedorf since 1954 Institute for Geodesy, Frankfurt am Main
1876	Straßburg (German Empire), Strasbourg, France (first light 1880, 16.0cm, 1.89m)
1877	Observatoire de Uccle, Brussels, Belgium (16.0cm, 1.95m, 1944 destroyed)
1877	Coimbra Observatory, Portugal (17cm, 1.95m, circle 96cm)
1874	US Naval Academy (USNA), Annapolis, Maryland (10.2cm, circle 72.9cm) 1908 to US Naval Observatory (USNO), Washington, D.C.
1882	Field Memorial Observatory, Williams College, Williamstown, MA, USA
1884	Washburn Observatory, Madison, Wisconsin, USA (12cm)
1885	Carleton College Observatory, Northfield, Minnesota
1886	Kuffner Observatory, Vienna-Ottakring, Austria (12.5cm) (Fig. 4 left)
1888	Lick Observatory, Mt. Hamilton, California, USA (16.2cm, 2.00m)
1891	Munich-Bogenhausen Observatory, Germany (16.2cm, 1.93m)
1892	Quito Observatory, Ecuador (16cm)
1893	Bonn Observatory, Germany (16.1cm, 1.94m)
1900	Breslau (German Empire), today Wrocław, Poland (16.0cm, 2.00m)
1901	Kremsmünster Mathematical Tower, Austria
1898	Heidelberg Observatory, Germany (16.2cm, 1.95m)
1902	Kiel Observatory, Germany (21.7cm, 3m)
1905	Charkow/Kharkov Uni. Observatory, Ukraine (16.0cm)
1905	Kazan, Engelhardt Astronomical Observatory, Russia (14cm)
1906	La Plata Observatory, Argentina (19.2cm, 2.26m)
1908	Santiago Observatory, Chile (19.2cm, 2.2m)
1908	Córdoba Observatory, Argentina (19.2cm, 2.3m) 1966 to OAFA, San Juan, Argentina
1909	Hamburg-Bergedorf Observatory, Germany (19.2cm, 2.3m) 1967 to Perth Observatory, Australia 1990 Deutsches Museum in Munich
1911	Poznan Observatory, Poland
1912	Porto Alegre Observatory, Brazil
1913	Berlin-Babelsberg Observatory, Germany
1913	Manila Observatory, Philippines

## 5. The Modern Computerized Meridian Circle

After work on the AGK 2 and AGK 3 project had been completed, the telescope was converted to photoelectric registration and transferred to Perth Observatory in Australia in order to produce a catalogue of stellar positions within the southern hemisphere (Behr, 1976). This paragraph shows this development of the photon-counting technology, invented by Erik Høg in Hamburg Observatory in the 1960s using Hamburg Observatory's first computer, the GIER (1964).<sup>31</sup> Using the Repsold meridian circle in Hamburg in the 1960s (Høg, 2014), Gerhard Holst was reading the declination circle and Johann von der Heide was observing the star with the visual micrometer. In 1964, the electronics for reading the declination circle was added: The paper tape punch and the electronics box *Zähllocher*, an identical box in the hut was used for the star observation, in addition to the visual micrometer, a photoelectric micrometer. In 1966, the first slit micrometer on a meridian circle was used. The instrument was semi-automatic with manual setting of the telescope and digital recording on 8-channel punched tapes of the star transit observation and of the circle readings (declination).

"I often visited the people working in the big Schmidt. I saw they noted the photometer reading on paper and later punched the numbers on cards to be processed in the IBM 650 computer in the city of Hamburg which was 20-km away." Inspired by Bengt Strömgren (1908-1987), who pioneered photoelectric astrometry by an experiment in 1925 (Strömgren Bengt, 1925), "I said the reading could be punched directly on cards. This was considered to be a good idea, so I designed and built the digital electronics." (Høg, 1960, p. 263)

The central idea was that starlight from the meridian circle would pass through a fixed grating and be detected by a photomultiplier tube. In this case the idea was not born out of any immediate local need, but because the technical possibilities for digital astrometry had come together in my mind. The idea was born from Strömgren's experiments with slits in 1925, from Naur's ideas about computers, and from what I had seen at the big technical fair in Hannover. But Otto Heckmann [1901-1983] immediately saw the

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<sup>31</sup> All the following quotations are from Erik Høg's interview about astronomy and astrometry up to 1980 (Perryman & Høg, 2021). Cf. (Høg, 2008-2011, n°8, p. 77-90).

potential for the planned expedition to Perth in Western Australia with the Hamburg meridian circle. This expedition was part of international undertaking by ten observatories. They should observe 20,000 stars of SRS, it was a Southern Reference Star catalogue. (Høg, 1960, p. 263)

Instead of using the old visual micrometers like the reference stars in the northern sky were observed, “with my digital method all observations could be punched on tape and be treated in a dedicated computer soon after.” The idea was tested on the Hamburg Meridian Circle between 1960 and 1967 (Høg, 2008a).

In 1967 the Hamburg meridian circle was dismantled, modernized and equipped with photoelectric reading and computerized using the *GIER* computer (1964), *Regnecentralen* of Copenhagen, with punched tapes — the first in the world (Høg, 2019). Then everything was shipped to Perth in Australia to measure the stars of the southern hemisphere. This digital method “became a success during the five years in Perth from 1967-1972, thanks to a very dedicated and capable team led by the experienced” Dr. Johann von der Heide (1902-1995) and the young technical assistant Gerhard Holst (1934-2000), and as a whole up to 10 observers. “Observation at the instrument was done by two people, usually a married couple. The wife set the star number on toggle switches and told her husband the declination of the star to be observed. He turned the telescope as needed and started the punching on tapes when he saw the star entering the field of view. So the instrument was in fact the first semi-automatic meridian circle, this was a revolution. It produced about 10 big rolls of tape every night.” And these were processed the next day on the *GIER* (*Geodetisk Instituts Elektroniske Regnemaskine*), “one of the first transistorized computers and it was crucial for the project because it was ten times faster than the cheapest IBM computer we could have afforded, but of course any laptop today is a million times faster than *GIER*. I had written all the programs in ALGOL 60, which was the new language to programming in which my former tutor Peter Naur (1928-2016) had a leading role.” (Høg, 2019)

In Perth, the fundamental catalogue FK4 was extended by 25,000 southern stars and the results (1969-1975) were published as *Perth-70* catalogue in 1976 (Høg & al., 1976). The work continued with the catalogues *Perth-80* and *Perth-83* until the operation of the meridian circle was finally stopped in 1987.

Errors of star positions and parallaxes in accurate catalogues are shown in Fig. 5. The error of a position in an observation catalogue improved from 0.9" in 1856 to 0.25" about 1910 (e. g. (Küstner, 1908)), and to 0.15" with the photoelectric observations in the Perth70 Catalogue (Høg & al., 1976).

The Hamburg meridian circle remained in Perth, Australia, until it was acquired by the Deutsches Museum in Munich in 1990. Preparations are made in 2019-2023, that the meridian circle — in exchange with Hamburg Observatory's large Zeiss blink comparator — can return to Hamburg in the restored meridian building. This is essential for the national Unesco application of Hamburg Observatory, submitted in Oct. 2021.

The next automated instrument was the Danish *Carlsberg Automatic Meridian Circle* at Roque de los Muchachos Observatory on La Palma in the Canary Islands, which came online in 1984 with an accuracy of  $\pm 0,003''$ . The CMC1-11 (1999) catalogues with the Carlsberg Meridian Circle were observed with a photoelectric slit micrometer similar to that one used for Perth70, but with automatic control of micrometer and telescope, giving a much higher efficiency (Høg, 2008c). The CMC14 catalogue (2006) was observed with CCDs, resulting in 0.034" accuracy from only two images of stars brighter than 13th mag. Comparable to the *Carlsberg Automatic Meridian Circle* (1984) are the *Tokyo Photoelectric Meridian Circle* (1985) or the 8-inch *Flagstaff Astrometric Scanning Transit Telescope* (FASTT), Farrand Optical Company (1981), recording with CCD camera, at the USNO Flagstaff Station Observatory.<sup>32</sup>

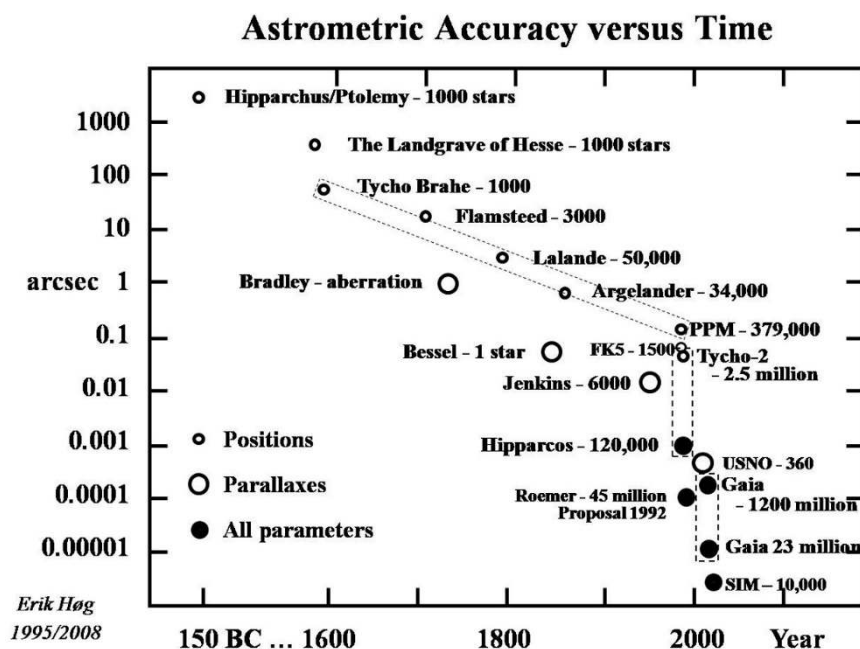
These photoelectric or CCD meridian circles mark the end of a long epoch of success, which paved the way for space astrometry, pioneered in France and implemented on *Hipparcos*, approved by ESA in 1980, and launched 1989 (Høg, 2008-2011, n°8, p. 77-90). "Photon-counting astrometry was also the basic measuring technique in *Hipparcos*. This technique was first implemented on the Repsold meridian circle for the Hamburg expedition to Perth in Western Australia where it worked well during 1967-1972."

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<sup>32</sup> [http://www.nofs.navy.mil/about\\_NOFS/telescopes/fastt.html](http://www.nofs.navy.mil/about_NOFS/telescopes/fastt.html) (2008). The Flagstaff Research Programmes were: Sloan Digital Sky Survey astrometric calibration, Near Earth Object astrometry — in collaboration with Lowell Observatory, Astrometry to support NASA spacecraft missions — in collaboration with Jet Propulsion Laboratory. Cf. (Stone & Monet, 1990).



Figure 5 - Astrometric accuracy during the past 2000 years



The accuracy was greatly improved shortly before 1600 by Tycho Brahe. The following 400 years brought even larger but much more gradual improvement before space techniques with the Hipparcos satellite started a new era of astrometry. Source: (Høg, 2008c, p. 2) reproduced from (Chapman, 1983, p. 135); © Erik Høg

The *Roemer* proposal of 1992 (Høg, 1993) introduced CCDs in integrating scanning mode in a space mission, instead of photoelectric detectors as in *Hipparcos*. *Roemer* promised a factor 10 better accuracy than *Hipparcos*. The CCD astrometry, explained in (Høg, 2008b), gives better accuracy because the stars are referred to the dense set of reference stars within the small field of the CCD in the *Tycho-2 Catalogue* of the 2.5 million brightest stars.<sup>33</sup> “The *Hipparcos/Tycho* results caused a revolution in astrometry impacting on all branches of astronomy from studies of the solar system and stellar structure to the measurement of cosmic distances and the dynamics of the Milky Way.” (Høg, 2019, p. 310) This successful development led to the successor

<sup>33</sup> ESA 1997, The Hipparcos and Tycho Catalogues, ESA-SP-1200. (Perryman, 2009).

of *Hipparcos*, the one million times more powerful *Gaia* astrometry satellite, launched by ESA in 2013.

## 6. Conclusion

In this article, a comprehensive overview of the technical development of the meridian circle is provided, using the contributions of the Repsold company (1799 to 1919) as a guiding light for three generations of Repsold meridian circles, delivered all over the world. A comparison with other German firms is presented.

Johann Georg Repsold (1770-1830) started the workshop in 1799, and — inspired by Ole Rømer (1704) — invented the first modern meridian circle (1802/03), an innovative instrument, which laid the foundations for a successful development of the Repsold firm. Several observatories ordered Repsold instruments, especially meridian circles, they were highly appreciated, but Repsold was not able to produce all of them, because he was not instrument maker by profession, only in his spare time. Thus, the competitors like the Mathematical-Mechanical Institute of Utzschneider, Reichenbach & Liebherr, the optical workshop Ertel of Munich, and Pistor & Martins of Berlin delivered more meridian circles in the beginning until the 1830s.

The sons of Johann Georg Repsold expanded their father's workshop and renamed it to Adolf & Georg Repsold (1830 to 1867). Their flourishing company produced telescopes, and especially meridian circles (second generation). They produced first a prototype for Hamburg, then they delivered meridian circles e. g. to Edinburgh in 1830, and to Pulkovo, St. Petersburg, in 1836, but also to Russia and Asia like Moscow, Kazan, and Georgia, as well as to the US Naval Observatory.

In the 19th century, positional astronomy with meridian circles played the dominant role. Around 1860 astronomy underwent a revolution; the quantity and quality of radiation was studied for the first time with physical and chemical methods — this was the beginning of modern “astrophysics”. The company was renamed in 1867 as Adolf Repsold & Söhne, and they broadened the offer of astronomical instruments, and especially high quality meridian circles with achromatic optics and technical improvements which could measure stellar coordinates with high precision. An impersonal micrometer, invented by Johann Adolf Repsold, increased the performance of

the reading accuracy. Especially the highly estimated catalogues of the Astronomische Gesellschaft, AGK 1 (16 observatories all over the world, including the southern sky with Argentina), AGK 2 to AGK 3, were produced with Repsold meridian circles in an international cooperation with Hamburg as the leading observatory. The Repsold company also offered the mounting and the building including the mire building (instead of simple meridian marks). In comparison to the beginning where an observatory building had only meridian slits, the modern meridian building with half cylindrical roof was constructed in a sophisticated way, e. g. with air flow for cooling. The Repsold company existed until 1919, and delivered around 70 instruments to Europe and overseas, to all continents — the Repsold company was a global player.

But also in the 20th century, some activities continued in the field of astrometry with meridian circles, but improved with photographic (1920s) and photoelectric (1960s) reading, and with CCDs (1990s). The photoelectric reading combined with punched cards was again introduced with the Hamburg meridian circle for the first time worldwide (1967), and realized during an expedition of several years to Perth Observatory in Australia, in order to measure the southern sky. A revival of astrometry came with the European ESA astrometry satellite *Hipparcos* (launched in 1989) and with the successor — first called *Roemer* (1992) — then *Gaia*, (launched in 2013). The former meridian circle catalogues are far surpassed in accuracy by the satellite-based astrometry observations, which provide the best possible stellar coordinates and other valuable data for astronomy and astrophysics. But e. g. for proper motions, the meridian circle catalogues since the 19th century are still of importance.

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### **Presentation of the author**

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